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A contribution to the analysis of historical economic fluctuations (1870-2010): filtering, spurious cycles and unobserved component modeling

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Abstract: Time series filtering methods such as the Hodrick-Prescott (HP) filter, with a consensual choice of the smoothing parameter, eliminate the possibility of identifying long swing cycles (e.g., Kondratieff-type) or, alternatively, may distort periodicities that are in fact present in the data, giving rise, for example, to spurious Kuznets-type cycles. In this paper, we propose filtering Maddison's time series for the period 1870-2010 for a selection of developed countries using a less restrictive filtering technique that does not impose but instead estimates the cut-off frequency. In particular, we use unobserved component models that optimally estimate the smoothing parameter. Using this methodology, we identify cycles of periods, primarily in the range of 4-7 years (Juglar-type cycles), and a number of patterns of cyclical convergence. We analyze the historical processes underlying this last empirical finding: peacetime periods, monetary arrangements, trade and investment flows, and industrial boosts are confluent forces driving the economic dynamism. After 1950, we observe a common business cycle factor that groups all economies, which is consistent with the consolidation of the so-called second globalization.

Keywords: historical business cycles, spectral analysis, unobserved component models, Maddison's time series

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1. Introduction

In a recent and suggestive paper, Diebolt (2014) claims to have identified a Kuznets-type cycle from a cliometric exercise based on the spectral analysis of Maddison's GDP series (Maddison, 2009; Bolt and Zanden, 2013). To this end, he proceeded to filter GDP series using the Hodrick-Prescott (1997) filter, and the spectra are estimated from the cycle component (deviation from the HP trend). In these spectra, a frequency corresponding to Kuznets-type cycles (approximately 20 years; Kuznets 1930, 1961) dominates. He also identifies a common component for the economies in the sample.[1] Finally, Diebolt attributes the existence of Kuznets cycles to a demographic cycle that would manifest in housing and infrastructure demand and discards explanations of the Kondratieff type.[2] An important problem with this filtering procedure is the possibility of inducing spurious cycles or other types of distortions in the filtered series when, for example, the smoothing parameter (in the HP filter) is imposed *a priori* (e.g., Pedersen 2001). Indeed, historical events could influence the period of the recorded fluctuations or cause structural changes in the parameters of the models employed (Darné and Diebolt 2004; Metz 2010). In the latter case, a flexible and parsimonious parameter representation could help to avoid the aforementioned problems.

The main difficulty in historically analyzing economic fluctuations, apart from the availability of reliable data, is the conceivable overlapping of waves of different periodicity (Schumpeter, 1939). When such analysis began, this fundamental question was not satisfactorily resolved because of the insufficient statistical and computational tools (Nerlove et al. 1979). Although time series analysis emerged during the 1930s (Yule 1927; Slutsky 1937; Wold 1938), the main econometric agenda prior to the 1970s centered on the linear regression model and its extension to simultaneous equation modeling (Epstein 1987, Morgan 1990, Hendry and Morgan 1995). The restatement of time series analysis in economics under the Box-Jenkins (1970) paradigm reawakened the former interest in unobserved components.[3] The decomposition of economic time series in trend and cycle (in addition to the seasonal and the irregular components) is clearly related to notions of secular evolution (long swings), which is eventually linked to long-term growth, and business cycle dynamics. Fortunately, we currently have a panoply of techniques at our disposal to efficiently address this problem (see Mills 2009); however, they are usually unknown and seldom applied in the analysis of historical time series.[4]

In this paper, we propose to estimate an unobserved component model to resolve this signal extraction problem, in which the smoothing parameter (a signal-to-noise ratio) is estimated optimally at the same time as the filtered components are obtained by means of the Kalman filter and the associated state space

[1] Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Italy, Japan, the Netherlands, Norway, Sweden, the UK, and the USA. In what follows, we add Spain and Switzerland.

[2] Discarding these types of results is trivial, as a sample of 140 observations would scarcely allow finding three complete cycles within a 50-year period.

[3] However, the Box-Jenkins methodology, based on differencing to achieve stationarity, eliminates long-term dynamics and obscures cyclical dynamics.

[4] An example is Cendejas & Font (2015), in which the price series of Hamilton have been modelled and analysed to obtain estimations of the common cyclical content of Spanish historical inflation.

expression of the model (Harvey 1989). This procedure does not introduce distortions by overweighting irrelevant frequencies or causing the appearance of inexistent cycles. Informally, we allow the data to "speak for themselves".

We apply this univariate unobserved component model to a sample of Maddison's GDP series.[5] We find a classical business cycle of a duration in the range of 4-7 years (Juglar-type cycles) and that there is no evidence of long swings or Kuznets-type cycles. Peacetime periods, monetary arrangements, trade and investment flows, and industrial boosts are confluent processes driving economic dynamism and producing a number of patterns of cyclical convergence in GDP series. Common factors capture the underlying common variation resulting from these patterns. Cyclical convergence is very strong after 1950, when cyclical phases between economies are synchronized (one factor grouping all of the economies has been found), and the standard deviation of the cyclical period is approximately one year. This fact coincides with the second wave of globalization and is supported by the periodicity established by economic historians (see, for example, Williamson 1996).

The remainder of the paper is as follows. In Section 2, we present, first, univariate unobserved component modeling and its frequency domain implications; second, we offer an outline of the usual static common factor methodology that we employ to explore the existence of common cycles from the components previously estimated; and third, we propose a multivariate common factor model that embodies common cyclical variation. In Section 3, the cyclical components are estimated, the existence of common cyclical factors across economies is discussed and, according to this finding, the multivariate common factor model is estimated. In particular, an increasing cyclical coherence is observed, especially after 1950. An explanation based on related economic history processes is provided.[6] The paper ends with some concluding remarks.

2. Unobserved component modeling

The possibility of reporting periodicities that are not truly really present in the observed time series as a consequence of the filtering method has been known since the 1930s. The so-called Yule-Slutzky effect (Yule, 1927; Slutzky 1937) consists in generating cyclical fluctuations only by summing and differencing a white noise process. Kuznets cycles of approximately twenty years have become a classical example of a "statistical artifact" (Adelman, 1965; Howrey, 1968). Kuznets transformed precisely the original series by averaging and differencing (Sargent 1979, pp. 248-251; Pedersen, 2001), causing the spectral gain of the implicit filter to show an important peak at the frequency of 20.25 years. If this filter is used to transform a

[5] In this paper, no attempt is made to discuss the statistical work; it is known that the database employed could influence the empirical results. Comparisons are always problematic and depend on the quality of the data (see Zarnowitz 1992).
[6] As Demeulemeester and Diebolt (2011: 2) suggest, it is important to reintroduce history and historicity in metric analysis. In this paper, we have attempted to combine both sides through a dynamic perspective, and we present an estimation method with an historical overview.

white noise process, a cycle of this period will be found. For time series distinct from white noise, this filter would favor the appearance of periods of approximately 20 years.

This distortion, in which the filter contains a cycle that passes into the filtered series, must be distinguished from the effects derived from imposing a cut-off frequency on economic series with the typical spectral shape, that is, series that concentrate variance in low frequencies (Granger 1966). In this respect, Nelson and Kang (1981) show how trend removal of a random walk process induces pseudo-periodic behavior in the detrended series, and Nelson (1988) shows how a random walk could be incorrectly decomposed into a relatively smooth trend and in a cycle. Concerning mechanical detrending, when the smoothing parameter λ is imposed in the HP filter, Harvey and Jaeger (1993) show how this procedure gives rise to cyclical behavior and propose structural models that simultaneously fit trend and cycle to avoid such pitfalls. Cogley and Nason (1995) argue in a similar vein. In all these cases, the periodicity found in the filtered series is not strictly spurious because the filter does not have a cycle, although some leakage and compression distortions have taken place.[7] In our view, in addition to the problem of correctly selecting the desired frequencies, it is important for these frequencies to be fundamental to business cycle dynamics. To address these questions, we propose allowing the data to locate the frequency in which the cyclical period is concentrated by optimally estimating the parameters in an unobserved component model.

The univariate model

The univariate model estimated here is the *Integrated Random Walk* (IRW) trend model (Young 1984; Harvey, 1989, 2010; Kitawaga and Gersch, 1996). Cendejas et al. (2014) employ its multivariate extension to a cyclical common factor model. The IRW model can be interpreted in terms of the growth and acceleration of the variables involved, and it is consistent both with the classical business cycle (expansion and recession states depending on the sign of GDP growth) and endogenous growth theory, in which many models establish the stationary state as a constant growth state, and consequently, the transitional dynamics represent a time path for which the second derivative is distinct from zero.

The univariate unobserved component model assumes that each of the observed series (which are expressed in logarithms) follows the equation

$$y_t = \mu_t + \varepsilon_t \tag{1a}$$

where μ_t is a non-stationary trend or level component and $\varepsilon_t \sim NID(0,\sigma_\varepsilon^2)$. In general terms, μ_t can be considered the signal and ε_t the noise, and hence we face a signal extraction problem. The trend μ_t is assumed to change with g_{t-1}

[7] An ideal band-pass filter would prevent these distortions by absolutely excluding the undesired frequencies (Pederse 2001; Gómez 2001; Harvey and Trimbu 2003).

$$\mu_t = \mu_{t-1} + g_{t-1} \tag{1b}$$

where g_{t-1} can be interpreted as the underlying growth rate of y_t, and therefore, changes in g_t, Δg_t, represent the acceleration of y_t

$$g_t = g_{t-1} + a_{t-1} \tag{1c}$$

where a_{t-1} is the acceleration. The acceleration, a_t, is characterized as white noise

$$a_t = \eta_t \tag{1d}$$

with $\eta_t \sim NID(0, \sigma_\eta^2)$ and uncorrelated with ε_t. Model (1a) to (1d) is the so-called IRW trend model or "smooth trend" model because of the absence of a noise term in (1b). The sign of the growth g_t could indicate a phase of expansion or recession under a classical business cycle understanding. By incorporating an acceleration component, we also consider declines and upturns in the growth rate. Additionally, the acceleration component is related in the frequency domain with the so-called growth cycle (upturns and downturns with respect to a trend), which is usually estimated by filtering with the HP filter (see Appendix A). Thus, the IRW model serves as a unified and coherent framework for modeling both types of cyclical dynamics: classical and growth cycles.

In model (1), as well as in the HP filter, the signal-to-noise ratio $q = \frac{\sigma_\eta^2}{\sigma_e^2}$ operates as a smoothing parameter and is the inverse of the smoothing parameter of the HP filter; that is, $\lambda = q^{-1}$. In particular, the lower is q (the higher is λ), the smoother is the trend component μ_t because the filter implied by the IRW model assigns greater weight to low frequencies when estimating the trend. Consequently, the detrended series, $y_t - \mu_t$, would incorporate a broader range of high frequencies. By imposing the value for $\lambda = 1600$ for quarterly series to obtain a cycle component, the range of frequencies is cutting out at a period of 9.9 years. For annual data, the usual value of $\lambda = 100$ divides the interval of frequencies at a period of 19.8 years. Thus, due to filtering by imposing λ, frequencies of a period longer than a certain duration will scarcely be present in the detrended series. In particular, if present, Kondratieff's long swings will not be found in annual series after detrending with $\lambda = 100$. On the contrary, the leakage distortion mentioned earlier will favor the appearance of cycles of approximately 20 years.

To avoid the risk of detecting cycles of distorted period, our proposal here is to optimally estimate the signal-to-noise ratio and allow the data to locate the frequency in which the cyclical period is concentrated. The state space form of model (1) (see Appendix B) allows the variances in q to be estimated by maximum likelihood using the Kalman filter (Harvey, 1989; Durbin and Koopman, 2001) and to obtain the predicted components (as conditioned by the information available up to $t-1$), the filtered components (as conditioned by the information available up to t) and the smoothed components (using the full sample). If we are interested in post-sample or historical analysis, the smoothed components are more appropriate. These components are the trend, $\hat{\mu}_t$, the underlying growth rate, $\hat{g}_t$, the acceleration, $\hat{a}_t$, and the deviation with respect to the trend, $\hat{C}_t^{HP} = y_t - \hat{\mu}_t$. The properties in the frequency domain, that is, the spectral gains of the filters implied by these four components, are described in Appendix A.

The spectral gain of a filter measures the increase in amplitude of any specific frequency component of a time series. The gains corresponding to the four components are represented in Figure 1. In this figure, the spectral gains of the filters for the trend, growth and acceleration components (the latter coinciding with that of $\hat{C}_t^{HP}$ when normalizing) have been represented using an example value $q = 0.01$ ($\lambda = 100$). The gains of the filters of $\hat{g}_t$ and $\hat{a}_t$ have been normalized in such a way that the gain is 1 in their maxima ($\omega_{\max}$ according to equation (A5) and π, respectively, with the original gains being $\frac{\sqrt{q}}{2}$ and q). With regard to $\hat{\mu}_t$ and $\hat{C}_t^{HP}$, their maximum gains are reached at the frequencies 0 and π with a gain of 1 in both cases. In view of this figure, the estimated components select the range of frequencies present in the observed series, with the weights corresponding to the gain (not normalized) of the corresponding filter. For example, in the trend, the frequencies will remain mainly below a period of 19.8 years; in the growth component, the frequencies around this period; and in the acceleration (or $\hat{C}_t^{HP}$) component, above this period. When imposing the smoothing parameter λ in the HP filter, $\hat{C}_t^{HP}$ may exclude frequencies that are important in the observed series. However, the estimation of λ leaves the data to locate the maximum gain in $\hat{g}_t$, that is, following a classical business cycle concept and, according to this period, the implied growth cycle $\hat{C}_t^{HP}$. This method simultaneously estimates both types of cycles, allowing for a more coherent analysis.

[Figure 1 about here]

Static common factors

Once the unobserved components have been estimated, we employ the underlying growth rates for the different economies, $\hat{g}_{it}$, to explore the presence of common growth factors during the sample period. Common factors are the underlying common variations resulting from the existence of common patterns in $\hat{g}_{it}$. They are obtained by synthesizing in a few variables (unobserved factors) the common information present in a wider set of variables. Let $y_t = (\hat{g}_{1t}, \hat{g}_{2t}, ..., \hat{g}_{nt})'$ be the vector of n underlying growth components. The vector y_t can be reduced to a simpler structure of m unobserved variables called factors with $m < n$. In what follows, the standardized variables, $x_{it} = \frac{1}{\sigma_{\hat{g}_i}}\left(\hat{g}_{it} - \bar{\hat{g}}_i\right)$, are considered, where $\bar{\hat{g}}_i$ and $\sigma_{\hat{g}_i}$ are the mean and the standard deviation, respectively, of $\hat{g}_{it}$. Each time series x_{it} can be written as

$$x_{it} = \lambda_{i1} f_{1t} + \lambda_{i2} f_{2t} + ... + \lambda_{im} f_{mt} + v_{it} = \lambda_i^{'} f_t + v_{it} \tag{2}$$

where λ_{ik} are the factor loadings, f_{kt} the factors, and v_{it} an idiosyncratic or specific error. In vector form, $x_t = \Lambda f_t + v_t$ with $x_t = (x_{1t}, x_{2t}, ..., x_{nt})'$, $\Lambda = \begin{bmatrix} \lambda_{11} & \lambda_{12} & \cdots & \lambda_{1m} \\ \lambda_{21} & \lambda_{22} & \cdots & \lambda_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ \lambda_{n1} & \lambda_{n2} & \cdots & \lambda_{nm} \end{bmatrix}$ the matrix of factor loadings, $f_t = (f_{1t}, f_{2t}, ..., f_{mt})'$ the vector of factors, and $v_t = (v_{1t}, v_{2t}, ..., v_{nt})'$ the vector of errors. Under the orthogonal (or classical) factor model assumptions, model (2) can be estimated by maximum likelihood by assuming that $x_t \sim N(0_n, \Gamma)$,[8] where $\Gamma = \Lambda\Lambda' + \Sigma b_t$ is the correlation matrix of x_t, and $\Sigma = \mathrm{E}\left[v_t v_t'\right] = diag(\sigma_{v_i}^2)$. Estimates of Λ and Σ are obtained under the constraint that $\Lambda'\Sigma^{-1}\Lambda = \Delta$, with Δ being a diagonal matrix. This condition ensures the identification of the factor model. From Γ, a variance decomposition is obtained for every x_{it}. In the diagonal of Γ, the correlation of x_{it} (trivially equal to 1) is $\rho(x_{it}, x_{it}) = c_i^2 + \sigma_{v_i}^2 = 1$, with $c_i^2 = \sum_{k=1}^{m} \lambda_{ik}^2$ being the communality of x_t (the percentage of correlation explained by the common factors) and $\sigma_{v_i}^2$ its uniqueness or specificity (the percentage of correlation not explained by the common factors).

The multivariate common factor model

Based on exploratory factor analysis, when the existence of a common factor grouping several economies can be accepted, a multivariate common factor model is estimated. The multivariate common factor model generalizes the IRW model by assuming common accelerations. Thus, equations (1a) and (1b) are merely sub-indexed accordingly

$$y_{i,t} = \mu_{i,t} + \varepsilon_{i,t} \tag{3a}$$

[8] The orthogonal (or classical) factor model is standard; see, for example, Tsay (2005: 426-429).

$$\mu_{i,t} = \mu_{i,t-1} + g_{i,t-1} \tag{3b}$$

with $\varepsilon_{i,t} \sim NID(0, \sigma^2_{\varepsilon_i})$ and uncorrelated across i s in all leads and lags, while the underlying growth components are assumed to follow

$$g_{i,t} = g_{i,t-1} + \gamma_i a_{t-1} + a_{i,t-1} \tag{3c}$$

Equation (3c) implies that changes in $g_{i,t}$, $\Delta g_{i,t}$, are the sum of a common acceleration component, a_t, shared with the other series in the model and an idiosyncratic or specific acceleration component, $a_{i,t}$. The parameter γ_i is the factor loading that acts as a scale factor that amplifies or reduces a_t (if positive; if negative, the variable would be countercyclical). Both acceleration components, a_t and $a_{i,t}$, are assumed to be white noise processes[9]

$$a_t = \eta_t \tag{3d}$$

$$a_{i,t} = \eta_{i,t} \tag{3e}$$

with $\eta_t \sim NID(0,1)$, $\eta_{i,t} \sim NID(0, \sigma^2_{\eta_i})$, mutually uncorrelated and with respect to $\varepsilon_{i,t}$ in all leads and lags. The variance of η_t is normalized to unity to allow the identification of the model. The specification of equation (3c) is based on the unobserved component model with a common cyclical factor proposed by Stock and Watson (1989, 1991) to obtain a coincidental economic indicator from first log-difference time series.

Given that the signal is $\mu_{i,t} = \dfrac{\gamma_i \eta_{t-2} + \eta_{i,t-2}}{(1-L)^2}$ and, analogous to equation (A1), the WK filter of the trend component is

$$\hat{\mu}_{i,t} = \frac{\dfrac{\gamma_i^2 + \sigma^2_{\eta_i}}{(1-L)^2(1-L^{-1})^2}}{\dfrac{\gamma_i^2 + \sigma^2_{\eta_i}}{(1-L)^2(1-L^{-1})^2} + \sigma^2_{\varepsilon_i}} y_{i,t} = \frac{q_i}{q_i + |1-L|^4} y_{i,t} \tag{4}$$

[9] Alternatively, a_t and $a_{i,t}$ could follow autoregressive processes if some cyclical persistence is present. In this case, equations (3d) and (3e) would be $\phi(L)a_t = \eta_t$ and $\phi_i(L)a_{i,t} = \eta_{i,t}$ with $\phi(L)$ and $\phi_i(L)$ being the respective autoregressive polynomials.

where the signal-to-noise ratio is now $q_i = \frac{\gamma_i^2 + \sigma_{\eta_i}^2}{\sigma_{\varepsilon_i}^2} = q_i^c + q_i^s$, with the ratios $q_i^c = \frac{\gamma_i^2}{\sigma_{\varepsilon_i}^2}$ and $q_i^s = \frac{\sigma_{\eta_i}^2}{\sigma_{\varepsilon_i}^2}$ expressing the signal-to-noise ratio decomposition due to the common and the specific components. In percentage terms

$$w_i^c + w_i^s = \frac{q_i^c}{q_i} + \frac{q_i^s}{q_i} = \frac{\gamma_i^2}{\gamma_i^2 + \sigma_{\eta_i}^2} + \frac{\sigma_{\eta_i}^2}{\gamma_i^2 + \sigma_{\eta_i}^2} = 1 \tag{5}$$

where the weightings, w_i^c and w_i^s, quantify the relative importance of the common and the specific variation in every unobserved component.

3. Empirical results and discussion

Hereafter, we present the estimation results[10] of the univariate IRW model for the Maddison GDP series and the exploratory analysis of common factors together with an economic history interpretation. An important finding is the existence of a unique common factor that groups all the economies in the sample beginning in 1950. This common factor allows us to estimate the multivariate IRW model (3) and to analyze the importance of the common business cycle in determining national business cycles.

	Full sample estimations				Sub-sample estimations		
				Duration of the cycles (years)			
	σ_ε^2	σ_η^2	$q = \frac{\sigma_\eta^2}{\sigma_\varepsilon^2}$	1870-2010	1870-1914	1915-1949	1950-2010
Australia	4.3868 (0.8709)	4.8908 (1.3122)	1.1149 (0.4439)	5.8 (0.64)	8.5 (1.46)	(*)	7.1 (1.87)
Austria	24.8728 (5.4456)	26.6981 (8.2012)	1.0734 (0.5001)	5.9 (0.76)	3.8 (na)	5.8 (1.37)	5.3 (1.17)
Belgium	4.5933 (1.0842)	5.6593 (1.7976)	1.2321 (0.6128)	5.7 (0.79)	6.0 (2.38)	5.4 (1.59)	6.5 (1.19)
Canada	4.1827 (1.0997)	13.7857 (3.2229)	3.2959 (1.4322)	4.3 (0.57)	6.7 (1.66)	3.0 (1.12)	5.3 (1.35)
Denmark	6.1104 (1.1549)	1.9121 (0.7653)	0.3129 (0.1652)	8.2 (1.14)	18.3 (3.57)	8.2 (2.63)	7.5 (1.49)
Finland	4.3643 (1.2129)	10.0232 (2.9024)	2.2966 (1.1809)	4.7 (0.72)	6.3 (1.52)	5.0 (1.64)	2.9 (2.25)
France	12.1745 (2.4542)	14.1720 (3.8118)	1.1641 (0.4688)	5.8 (0.64)	(*)	5.4 (1.37)	5.0 (1.26)
Germany	10.6739 (4.3631)	47.3368 (14.4031)	4.4348 (2.9730)	3.9 (0.84)	9.1 (2.75)	3.6 (1.70)	9.1 (1.73)
Italy	1.5268 (0.9726)	19.9553 (4.8363)	13.0701 (10.9305)	2.5 (1.28)	11.2 (2.37)	(*)	6.4 (1.39)
Japan	19.6793 (3.6905)	11.8675 (3.7053)	0.6030 (0.2607)	6.9 (0.80)	29.6 (12.45)	6.1 (1.59)	4.5 (1.07)
Netherlands	12.2482 (3.1892)	19.1989 (6.1466)	1.5675 (0.8275)	5.3 (0.79)	11.2 (3.71)	5.4 (1.88)	4.4 (1.10)

[10] The estimation results of Tables 1, 3 and 4 were obtained using Matlab R2010b ©. We observed that there are some estimation differences resulting from the Matlab version employed when running the code.

Norway	4.3379 (0.8548)	2.9147 (0.9394)	0.6719 (0.3060)	6.7 (0.82)	4.4 (1.47)	7.3 (1.74)	3.5 (1.19)
Spain	5.6170 (1.4850)	6.7703 (2.4701)	1.2053 (0.6992)	5.7 (0.92)	15.4 (4.89)	4.8 (1.75)	2.9 (1.08)
Sweden	3.3955 (0.6462)	2.2589 (0.6948)	0.6653 (0.2867)	6.7 (0.78)	15.9 (3.94)	6.1 (1.62)	5.5 (1.61)
Switzerland	13.1640 (2.4468)	1.6913 (0.8971)	0.1285 (0.0846)	10.3 (1.76)	35.1 (15.56)	9.0 (2.14)	4.1 (2.20)
UK	0.7992 (0.3031)	6.3568 (1.3476)	7.9541 (4.2523)	3.2 (0.65)	3.4 (1.26)	2.6 (1.55)	3.4 (2.34)
USA	4.3795 (1.2259)	17.5426 (3.9837)	4.0057 (1.7852)	4.0 (0.57)	10.5 (2.73)	(*)	6.1 (1.45)
			Mean period	5.6	12.2	5.6	5.3
			Standard deviation	1.9	9.1	1.8	1.7

Table 1. Full sample estimated variances of the univariate IRW model (1) and the duration of the cycles derived from the estimated parameter q according to equation (A5) for full sample and sub-sample data. (*) In these cases, the important noisy content of the original data passes into the signal, causing $q > 16$ and preventing the period from being computed according to equation (A5).

Table 1 reports the estimated variances from the full sample using the univariate IRW model (1) and the periods (duration of the cycles) derived from the estimated parameter q according to equation (A5). Model (1) has also been estimated in sub-samples corresponding to the pre-, inter- and post-war periods. Full sample estimations show a mean duration of 5.6 years with a standard deviation of 1.9 years. The durations range from the 2.5 years[11] observed for Italy to the 10.3 years observed for Switzerland. For the Swiss economy, the implied smoothing parameter value $\lambda = q^{-1} = 7.78$ (which is larger in full sample estimations) shows the inadequacy of imposing $\lambda = 100$ when filtering annual data. The duration characteristics of long swings and Kuznets cycles are clearly excluded. A period in the range of 4 to 7 years is present in 13 of the 17 economies. Regarding the sub-samples, the mean duration increases to 12.2 years in the pre-war period with a high standard deviation of 9.1 years. These figures are substantially influenced by the long periods estimated for Denmark, Japan and Switzerland. The mean durations in the inter- and post-war periods are 5.6 and 5.3 years, respectively, with standard deviations of 1.8 and 1.7 years. When the original Maddison series are supposed to be more reliable (post-WWII period), the durations range from 2.9 years (Finland and Spain) to 9.1 years (Germany). For the USA and the post-war sub-sample, our estimated period (6.1 years) is not very different from that of the NBER (5.7 for the period 1945-2009).[12]

[11] Some periods close to 2 years are influenced by the noisy content of the original data that pass into the signal. Consequently, the signal-to-noise ratio is high. For $q > 16$, the frequency exceeds π and the period would not be observable (Nyquist frequency).

[12] http://www.nber.org/cycles.html. Regarding the average duration of business cycles for 13 developed countries, Bergman *et al.* (1998) obtain some different results. This is a consequence of both the different filtering methodology (they used a band-pass filter that imposes a range of duration of the business cycle of between 2 and 8 years) and the databases employed.

From 1870 to 1914, Switzerland experienced a long cycle coinciding with the higher growth rate (1.7% annually) observed among the developed European countries due to a combination of political stability, long-term investment in industry, FDI (Puig and Castro 2009) and an emerging and solid financial system. Switzerland, similar to other small countries such as Belgium, Denmark or the Netherlands, owing to the small size of domestic markets, became an open economy by developing a competitive export sector and several forms of protectionism to secure the domestic market for Swiss industries (David and Mach 2007: 220-222).[13] Other economies also opened during this period. This was the case for Japan: the forced opening of the Japanese domestic market during the first wave of globalization—during the Meiji Era—was spectacular. Total trade increased from 10% of GDP in 1870 to 30% in 1910 (Baldwin and Martin 1999: 15). Sweden (total trade 40% of GDP), Norway (69% of GDP) and Denmark (60% of GDP) also experienced considerable openness before WWI. However, some Western economies adopted protectionism and technological renewal to overcome the first adverse shocks—the depressions of 1873 and 1896—resulting from globalization (Fernández de Pinedo 2012: 52).[14] Although the first globalization (1870-1914) consolidated, several cycles overlapped, and developed countries had to cope with numerous crises that affected their economic structures while the gold standard was moving toward consolidation.

After the Franco-Prussian War and the reparations imposed on France, Germany favored the development of joint stock companies (1870) and the concentration and vertical integration of its firms. Moreover, the territorial unification of 1871 led to a real estate boom and the emergence of banks, especially the rapid increase in the number of companies converted to banks (Maklerbanken or Baubanken), in an effort to create a hierarchical banking structure based in Berlin (Kindleberger 2006: 125, 127). However, the stock market crash of 1873 became a depression, intensifying the process of cartelization until 1879 (Flamant and Singer-Kerel 1971: 41 & 44)[15]. On the other side of the border, after the loss of Alsace (1871), France also had to overcome the crunch of 1873.[16] Agricultural trade unions, agricultural credit societies and investment in inputs and machinery were able to ameliorate the agrarian crisis. A public works program—the Freycinet Plan—and the rise of the consumer goods industry also improved French performance, as did a new tariff policy implemented in 1881-1882 (Lavisse and Rambaud 1901: 774). However, growth slowed again between 1882 and 1886 as a result of the continued decline in prices, damaging bankruptcies[17] and

[13] As Sáiz (2014) has noted, the Netherlands, Switzerland, and Denmark were patentless economies in nineteenth century that benefited from relaxed IPR regimes and thus became leaders in specific sectors.

[14] The Spanish agriculture sector lost thousands of migrants to the Americas but simultaneously received a considerable amount of FDI from France and Germany (Puig and Castro 2009), although these investments favored foreign over domestic firms.

[15] At the turn of the century, the second energy revolution led to an electricity crisis, causing a new wave of mergers, this time among the main electricity companies between 1902 and 1903 (Flamant and Singer-Kerel 1971: 45). USA orders began to decrease in 1906, and a crisis in the German textile sector emerged in 1908 followed by a crisis in the machinery industry in 1909, prompting an obvious contraction of German foreign trade and declining reserves at the Reichsbank. However, German production would focus on foreign markets, and the country held a surplus in its trade balance until 1913.

[16] French agriculture had been subject to foreign competition since 1880 due to the decline in the cost of transport. Grain prices were not the only ones suffering declines. France shifted from being an exporter of wine to being an importer of 10 million hectoliters in 1890 despite attempts to prevent the phylloxera blight in the early 1850s. Agricultural setbacks were partly offset by the growth in the cattle industry and the rise in the consumption of meat (Lavisse and Rambaud 1901: 767).

[17] Banque de Lyon et de la Loire, Union Générale.

limited demand. The recovery of France was slower owing to the scandalous bankruptcy of the *Compagnie Universelle du Canal Interocéanique Panama* (Bouvier 1964), and the failure of the Société des Métaux (1889).[18] These setbacks led to a credit crunch and the establishment of the Méline protective tariff (1892). Investments in Russia favored French industry in the form of orders until that capital vanished with the Russian Revolution.

The USA was, after Germany, the second nation shaped by the railway and banking crisis of 1873, also known as Jay Cooke's panic (Flamant and Singer-Kerel 1971: 25). A new railway crisis in 1882-1884 meant the end of the railway boom as an instrument of growth and was replaced by falling prices in the primary sector (cotton and wheat), highly protectionist legislation (the McKinley tariff of 1890) and a commitment to silver[19] (Kindelberger 2006: 284). After several crises between 1903 and 1907,[20] a new banking system was created with the establishment of the Federal Reserve System, as well as new antitrust laws and tariff reductions in the Underwood Tariff of 1913 (Chang 2008: 54). Despite these setbacks, the USA grew faster than other Western countries at this stage.

The UK was not immune to the crisis of 1873; however, capital investments abroad (to Argentina Australia, and Canada) multiplied at the end of the century and allowed the UK to finance imports. After several setbacks,[21] a process of concentration, featuring mergers not only in manufacturing but also in the banking system, took place. As a result, leading UK commercial banks dominated the British financial market (Flamant and Singer-Kerel 1971: 46).

Table 2 shows the results of the estimation of the static factor models. The sample period has been divided into the three major historical periods previously considered.[22] The main results are coherent with those observed in Table 1. A noisier pre-war period is accompanied by the absence of a common factor grouping for all economies. Two common factors have been found (Factor 1 and Factor 2). Factor 1 is significantly correlated with 10 of the 17 economies. The largest correlations correspond to Germany (84%), Belgium (82%) and Austria (80%). The list of economies primarily represents continental Europe and the USA and Canada, although, in the latter two cases, the communalities (the percentage of the variance explained by the factors) are small. Consequently, Factor 1 primarily reflects a Central European business cycle. The second factor (Factor 2) significatively includes the Scandinavian economies (Norway, Sweden and, perhaps, due to a non-significant correlation, Finland), France, the UK and Spain. In general, the communalities show a moderate explanatory power of the factor model that is consistent with the absence of global cyclical integration. The exceptions are Austria, Belgium, France and Germany, which exceed

[18] Bulletin Financier, p. 812. Revue des Sciences et des Lettres, 1/01/1889.
[19] Sherman Silver Purchase Act.
[20] This was the so-called "Rich man's panic" (1903-1904), which originated in the steel trust and affected the mining and steel industry. In 1907, the urgent need for means of payment, stock accumulation and the scarcity of gold prompted a currency crisis that forced USA banks to suspend payments. (Flamant and Singer-Kerel 1971: 48).
[21] The depression in the UK that emerged during the crisis of 1882 would last until 1886-1887. This was followed by the collapse of Barings bank in 1890 due to its role as the financial agent for the poorly economically performing Argentine Republic. The economy suffered again with the 1907 US crisis, particularly affecting industry, that led to major strikes in the textile sector.
[22] For a different periodization, see, among others, Foreman-Peck (2007) and Northrup (2005). The one employed here is fairly coincident with that of Maddison (2007).

50%, mainly due to Factor 1. The significance of Factor 2 is mainly due to Norway and Sweden and could be interpreted as a peripheral factor grouping economies excluded from Factor 1 (negative loadings do not have any special interpretation in this context). When a third factor is added to the model, the communality increases minimally in some cases at the cost of some reductions in others; thus, no further integration, in the form of clear dependence on common factors, can be found (this is also the case for the other periods). These factors and their relationship with the estimated growth components, $\hat{g}_t$, can be seen in Figure 2.

	1870-1914			1915-1949			1950-2010		
	Factor 1 loadings	Factor 2 loadings	Communality	Factor 3 loadings	Factor 4 loadings	Communality	Factor 5 loadings	Factor 6 loadings	Communality
Australia	0.23	0.05	0.05	-0.19	**0.56**	0.35	**0.49**	**0.62**	0.63
Austria	**0.80**	**-0.37**	0.78	0.20	**0.98**	1.00	**0.80**	**-0.31**	0.73
Belgium	**0.82**	-0.07	0.67	**0.85**	-0.01	0.73	**0.87**	0.15	0.78
Canada	**0.48**	0.08	0.24	-0.28	0.36	0.21	**0.61**	**0.58**	0.71
Denmark	**0.50**	0.11	0.26	**0.79**	-0.18	0.66	**0.75**	0.17	0.59
Finland	**0.46**	0.24	0.27	**0.47**	0.25	0.29	**0.69**	**0.33**	0.58
France	**0.65**	**0.54**	0.71	**1.00**	0.00	1.00	**0.99**	-0.07	0.98
Germany	**0.84**	-0.02	0.70	-0.27	**0.79**	0.70	**0.69**	**-0.32**	0.58
Italy	**0.35**	-0.28	0.20	**0.67**	0.35	0.56	**0.86**	-0.13	0.76
Japan	0.02	0.04	0.00	-0.12	**0.81**	0.67	**0.85**	-0.28	0.80
Netherlands	0.22	-0.03	0.05	**0.89**	0.14	0.80	**0.72**	0.23	0.57
Norway	0.14	**0.83**	0.71	**0.88**	-0.03	0.77	**0.50**	**0.31**	0.35
Spain	0.17	**0.36**	0.16	-0.16	0.06	0.03	**0.81**	0.22	0.70
Sweden	-0.05	**0.68**	0.46	**0.77**	-0.04	0.60	**0.71**	**0.38**	0.65
Switzerland	**0.33**	**-0.42**	0.28	**0.61**	0.10	0.38	**0.75**	-0.16	0.59
UK	0.19	**0.39**	0.19	-0.35	**0.48**	0.36	**0.40**	**0.63**	0.56
USA	**0.37**	-0.19	0.17	**-0.58**	0.34	0.45	**0.55**	**0.46**	0.52

Table 2. Estimated factor models. In bold: correlation with the common factor statistically significant at the 0.01 level.

[Figure 2 about here]

Factors 1 and 2 represent both the outcome of the first globalization and of the second industrialization process that took place during the period from 1870 to 1914, also known as the *Belle Époque*. Despite the first modern crisis of overproduction – the Great Depression of 1873 –[23] it seems that "positive shocks"

[23] Germany and the United States were affected by the crisis that started with the crack of Vienna on the 8th of May 1873 as a consequence of speculation, rising costs and declining corporate profitability. From Central Europe, the crisis moved to the Atlantic and reached the USA in September 1873. The depression lasted until 1879. The industrial sector suffered markedly. Even the UK faced large bankruptcies, 13,130, only in 1879. Prices and wages dropped (Flamant and Singer-Kerel 1971).

had a much deeper impact on the growth trend than did “negative shocks”. A considerable degree of economic openness, a solid international monetary system, and the consolidation of centralized nation-states (Germany and Italy) favored stability and the integration of the international economy. It is necessary to emphasize that the period of greater liberalization in the world economy – in migration, capital and trade – occurred between 1870 and 1914, a period of peace after the last European wars (the Napoleonic and Franco-Prussian wars). Industrial Enlightenment (Mokyr 2010) in Great Britain and the spread of the Industrial Revolution provoked a trend toward convergence among European economies. The first-comers (Belgium, France, and Switzerland) and the latecomers (Germany, Italy and Austria-Hungary) enjoyed the *Pax Europa* (Craig and García-Iglesias 2010: 124) under an open trade area[24] after the Cobden-Chevalier treaty of 1860, with a parallel leading role for the UK as the emerging “globocop” (Morris 2014: 25, 271) and its *Pax Britannica* on the seas. In addition to trade liberalization, monetary stability was reached after the majority of European industrialized countries and the USA (1879) joined the gold standard (Germany in 1872, Belgium, France and Switzerland in 1878, and Canada in 1853).

Increased productivity reduced production costs in agriculture and manufacturing, and the impact of technical improvements and the transport revolution, together with the opening of the Suez Canal (1869), prompted the decline in international freight rates and in domestic transport costs with the spread of railroads in Europe and the transcontinental railroad in the USA (1869). Intra-European migration, followed by massive international migration beginning in 1875, had an enormous impact on wage convergence. International flows of labor and capital permitted the USA and Canada to join the club. Nordic countries (Factor 2) also caught up (Bruland and Smith 2010) beginning in the 1870s, taking advantage of natural resources, global capital and labor markets and the flow of new technological know-how.[25] Nordic economies sent working populations to the USA and received large amounts of capital from France and Germany beginning in the mid-nineteenth century. France and the UK became major exporters of skilled labor, machinery and capital in the nineteenth century thanks to their preeminent industrial leadership.

[Figure 3 about here]

The second period (1915-1949) shows a higher correlation of the growth components with the estimated factors (Factor 3 and Factor 4). In general (except for Canada and Spain)[26], the communalities are greater than in the pre-war period as a consequence of common devastating shocks such as the world wars and the depressions of 1920-21, 1929-1933 and 1937-38. The two factors include disjointed sets of economies.

[24] “International trade is perhaps the most important form of engagement with the world economy” (Nayyar 2009: 14).

[25] Nordic countries, in addition to their cultural proximity, had a late and rapid industrialization based on institutional reforms that eliminated restrictions on business, innovation and credit (banking system). They combined rich natural resources such as forests, ore deposits, fishing, land and oil with a late integration into the globalization process, in addition to mergers and acquisitions between large firms and, after WWII, the expansion of the public sector and welfare system (Henning et al. 2011). The impressive progress made the Nordic countries “an overachiever” (O’Rourke and Williamson 1995: 8), although there were differences between countries, Sweden being the country that made the most rapid transition.

[26] The Spanish Civil War (1936-1939) may have affected this result.

Factor 3 is identified with the growth component of France (correlation of 100%) and also includes Belgium, Denmark, Finland, Italy, the Netherlands, Norway, Sweden and Switzerland. Factor 4 is significatively correlated with Germany and also includes Australia, Austria, Japan and the UK. This grouping indicates the different cyclical patterns present, particularly from the 1930s, as seen in Figure 3, when comparing both factors: they move in parallel until 1937; in that year, Factor 3 diminishes and recovers beginning in 1941, reaching a maximum in 1946. Factor 4 diminishes from 1940 until 1945 and then recovers. Thus, the different cyclical effects of WWII are shown by these factors, both during the war and the immediate post-war period (e.g., the negative and significant correlation of the USA with Factor 3).[27]

The inability to create a stable international system after WWI ultimately resulted in WWII. War was an exogenous factor that had negative effects on economic output (Feinstein et al. 2008) and represents a downturn that involves multiple countries with different trajectories. The state had to intervene in the economy to solve problems related to economic restructuring. The implementation of a war economy meant that investments in strategic sectors (heavy industry, railway networks, and the arms industry) had to be prioritized at the expense of light industry and agriculture. In accordance with the disruption of commerce and agricultural production and the destruction of infrastructure, convertibility was suspended, affecting balance of payments adjustments. Finally, the post-war recovery and reparations from WWI, as well as changes in frontiers, with new countries emerging and others disappearing (Singleton 2007: 11),[28] all suggest de-globalization (Williamson, 1996). Wars and the depression of the 1930s stopped capital, migration and goods flows (Siegfried 1937[1995]: 422), interrupting the tendencies that began in 1870. War is the opposite of peace, which "together with law and order, plays a key role in allowing the market to extend and creating increasing returns" (Foreman-Peck 2007:24).

The two wars had different ultimate impacts on national economies. WWI interrupted the industrialization process of some countries due to the lack of foreign direct investment and technology imports. The United States and Japan, as well as peripheral countries, become the main beneficiaries of the European conflict after capturing markets abandoned by a Europe involved in war. The balance of economic power moved to the Pacific. WWI was a great business for certain economies. Between 1913 and 1929, the European neutrals (the Nordic countries, the Netherlands, and Switzerland) experienced faster growth than the combatants. Switzerland between 1914 and 1949 made a transition to the second Industrial Revolution at rapid pace, especially in the machine tool industry (Donzé and Martí 2014), energy and financial sectors. The two world wars greatly facilitated this specialization because of the country's neutrality, and it overcame a monetary crisis thanks to a stable Swiss Franc (David and Mach 2007). Except for the UK,

[27] Technology transfer of military origin to the civilian sector (Fernández-de-Pinedo and Muñoz 2014) was very important, as in the case of aviation, antibiotics, industrial restructuring, the explosives industry and fertilizers.

[28] As Singleton noted, geography changed. France received Alsace and Lorraine from Germany, but "Poland was created out of land formerly belonging to the German, Russian and Austro-Hungarian Empires. The heartland of the Austro-Hungarian Empire was divided into the independent nations of Austria, Hungary and Czechoslovakia. Russia was stripped of Lithuania, Latvia, Estonia and Finland …" (Singleton 2007).

which was particularly vulnerable to the dislocation of international markets, the European Allies outperformed the former Central Powers. War imposed output losses on many countries and altered the long-term rate of growth of the UK.

When peace returned, the industrialization process accelerated, spurred by the recovery policies focusing on investments in modern technology (chemistry, electricity, cement). The recovery from the war was uneven. Financial costs and the economic consequences of the war prevented a return to the situation that prevailed in July 1914. Inflation and deficits were the main imbalances that affected, in different ways, the various countries in the early post-war years. The return to the gold standard at pre-war parities proved to be a difficult task for the European countries. Only neutrals and the UK achieved this objective. Finland, Belgium, France and Italy returned to gold with reduced parities and enjoyed greater economic growth than the UK. Factor 3, by grouping these countries, demonstrates the consequences that these adjustments had for growth. Germany and Austria also returned to the gold standard after the large depreciations and the hyperinflation of the 1920s.

When European production capacity returned to normal, both in agriculture and industry, the problem of overproduction emerged because the production capacity of non-European countries had greatly increased, and overproduction became chronic (Eichengreen 1992). The crisis lasted from three to four years, from 1929 to 1932-33. Protectionism since 1930 meant a return to quotas, import substitution policies and, in the case of some countries (Germany, Italy, Japan and Spain), tendencies toward economic autarky (Bouvier 1995: 381) and authoritarian regimes. As a result, economies tended to reduce imports and restrict capital flows, and foreign trade was controlled by the state. The countries most affected were those that had been defeated in the war, while those only slightly affected were the Scandinavian countries: Denmark's GDP did not decrease, and others only moderately decreased, such as those of Spain and Italy (Maddison, 2001). In general, small neutral countries such as Switzerland, the Netherlands, Denmark and Sweden managed to adapt to new models of competitiveness and discovered niche markets. Some of the great multinationals linked to these countries successfully managed to enter the world market and consolidate their positions in these years.

After the recovery from the Great Depression, both Germany and Japan began to prepare their economies for war. The unstable international market collapsed for the third time in less than thirty years. During WWII, the entire continent, except four countries that remained neutral, was occupied. For the first time, their economies were unified under a single yoke. Hitler achieved the total economic and political reconstruction of Europe to make it self-sufficient. GDP did not increase throughout belligerent Europe, but the USA doubled per capita income after recovering from the Great Depression.

[Figure 4 about here]

Finally, stage three (1950-2010) reflects the global convergence of Western Europe and the Anglo-Saxon, economies headed by the USA, and the return of a greater degree of economic openness as a consequence of the second globalization. Therefore, the post-war period is characterized by global cyclical integration as shown by the communalities in Table 2, in which values are more homogenous and, in most cases, higher than in the previous periods. Plots in Figure 4 show the increasing cyclical coherence during the period. Consistent with this, a common factor including all of the economies is found (Factor 5), while the second factor of the model (Factor 6) captures some specific growth present in the Anglo-Saxon economies (Australia, Canada, UK and the USA), primarily after the 1980s (see Figure 4), as well as some Scandinavian particularities (Finland, Norway and Sweden[29]). Factor 5 is identified, as in the previous period, with the growth component of France and could be viewed as a precursor to a European Union business cycle. It is important to note its decreasing profile. When comparing both factors, Factor 6 shows the higher growth present in the mentioned economies from the 1980s, which can be related to the liberalizing policies present in these economies.

In the post-war period (see Factor 5), a convergent trend began with the European recovery plan (Marshall Plan 1948-1957) and the establishment of the Bretton Woods System (1944-1971). The regulation of trade through GATT in 1947, the Treaty of Rome, which established the European Community in 1957, and the European Free Trade Association two years later intensified economic integration. Japan and Western Europe performed much better and greatly reduced the gap between their income and productivity levels with respect to those of the USA. In Western Europe, this catch-up process provided the opportunity to recover from the lost opportunities resulting from the war. The Japanese catch-up process was spectacular. Japan, which had devoted a large part of its human and capital resources to military ends since the Meiji Period, had to complete de-militarization. This meant, as in the case of Germany, that its skills, organizational capacity and investment were devoted almost entirely to economic growth through capital-intensive technology. Japan and Germany grew thanks to the industry-bank-R&D nexus in the aftermath of the war, while avoiding military spending. During the 1980s, the end of the Cold War and the integration of Eastern Europe caused convergence to accelerate, while the merger of the EU market and the adoption of the Maastricht Treaty in 1991 deregulated economic activities. Regional integration spread through multilateral free trade agreements, and customs unions or common markets spread over five continents. Despite several frequent international periods of stagnation and stock market bubbles beginning the 1970s (oil price shocks, the great inflation of the 1970s and 1980s and the recession of the 1990s) until the 2007 global financial crisis,[30] the convergence of the Western European, Japanese and Anglo-Saxon economies seems to be an incontestable fact.

In sum, two relevant factors seem to influence trends:[31] the relevance of international politics, understood as a process that enhances or boosts cooperation, and the significant role of the institutional framework, in particular as it is linked to international payment mechanisms and monetary arrangements, which in turn encourage trade.

Finally, to quantify the importance of this global business cycle factor for national economies, the multivariate common factor model (3) is estimated for the post-war period. In so doing, we have a measure

[29] The Swedish banking crisis of 1990-94, and the strong monetary policies and structural reforms that government had employed to recover, should not be forgotten.

[30] From the mid-1980s until 2007, the gradual reduction of inflationary trends in the industrialized world was referred to as the “Great Moderation” thanks to the reduction in the volatility of GDP growth in Australia, Canada, the USA, the UK, Germany, Japan, France and Italy (Summers 2005).

[31] For other approaches that examined business cycle fluctuations and monetary policy regimes, see Bergman et al. (1998); Milanovic (2005); and Piketty and Saez (2006).

of the importance of the common factor grouping all of the economies (i.e., a global factor) with respect to business cycle dynamics. The estimation results are shown in Table 3. All of the factor loadings are significatively different from zero, verifying the existence of a global common business cycle factor that displays the acceleration shared by all the economies in the sample. According to equation (5), the relative importance of this common behavior has been computed, with the result that it exceeds 50% in 15 cases, the exceptions being Norway (24%) and Spain (21%); and exceeds 70% for 9 economies. The more important specific cyclical variation in decreasing order corresponds to Spain (79%), Norway (76%), Denmark (45%), UK (44%), USA (43%), Canada (43%) and Japan (42%). It must be noted that these estimates are averages for the period, and some progressive increase in the weighting of the common factor could have taken place in some cases. Across the specific components, $a_{i,t}$, some important positive correlations would support the possibility of estimating a minor common factor grouping Australia, Canada, Denmark, Norway, UK and the USA, which is consistent with the previous exploratory factor analysis. The periods obtained from q_i differ in some cases from those of Table 1. In general, the duration is lower than that presented in Table 1. In the range from 4 to 7 years, we find 5 of 14 economies; in the range from 3 to 8, we find 11 of 14 economies. The mean duration is 3.9 years with a standard deviation of 1.2 years.

	$\sigma^2_{\varepsilon_i}$	$\sigma^2_{\eta_i}$	γ_i	Importance of the common cycle w_i^c	Importance of the specific cycle w_i^s	$q_i = \frac{\gamma_i^2 + \sigma^2_{\eta_i}}{\sigma^2_{\varepsilon_i}}$	Duration of the cycles (years)
Australia	1.4482 (0.5101)	0.2163 (0.2432)	0.7935 (0.2574)	0.74	0.26	0.5841 (0.3623)	6.9 (1.16)
Austria	0.5060 (0.1695)	0.6792 (0.2893)	1.8259 (0.2290)	0.83	0.17	7.9309 (3.4917)	3.2 (0.54)
Belgium	0.3240 (0.0954)	0.1380 (0.0831)	1.7747 (0.1654)	0.96	0.04	10.1459 (3.8023)	2.8 (0.48)
Canada	1.2840 (0.4146)	1.1422 (0.5643)	1.2345 (0.3022)	0.57	0.43	2.0764 (1.0414)	4.9 (0.71)
Denmark	1.3732 (0.4478)	0.9577 (0.5285)	1.0865 (0.2848)	0.55	0.45	1.5571 (0.9965)	5.3 (0.96)
Finland	0.4937 (0.3015)	2.6489 (1.0309)	2.7795 (0.3341)	0.74	0.26	21.0148 (13.9352)	(*)
France	0.1990 (0.0921)	0.0954 (0.1037)	1.4242 (0.1311)	0.96	0.04	10.6699 (5.3239)	2.8 (0.65)
Germany	0.8588 (0.2448)	0.4125 (0.2142)	1.4304 (0.2318)	0.83	0.17	2.8630 (1.3829)	4.4 (0.65)
Italy	0.5113 (0.2400)	0.8092 (0.4570)	1.4973 (0.2410)	0.73	0.27	5.9677 (4.1657)	3.5 (0.85)
Japan	0.5353 (0.2322)	1.9673 (0.7013)	1.6592 (0.2800)	0.58	0.42	8.8185 (4.9944)	3.0 (0.70)

Netherlands	0.7716 (0.5132)	0.7879 (0.8385)	1.6224 (0.2848)	0.77	0.23	4.4327 (3.6168)	3.9 (1.03)
Norway	0.2160 (0.1343)	1.6626 (0.5790)	0.7190 (0.2198)	0.24	0.76	10.0887 (8.4324)	2.9 (1.07)
Spain	0.6993 (0.3722)	3.7701 (1.3865)	0.9936 (0.3524)	0.21	0.79	6.8033 (4.8463)	3.3 (0.87)
Sweden	0.0286 (0.1008)	2.2499 (0.6843)	1.8686 (0.2093)	0.61	0.39	200.9064 (718.2435)	(*)
Switzerland	0.7762 (0.2231)	0.3520 (0.1945)	2.2028 (0.2365)	0.93	0.07	6.7049 (2.4734)	3.4 (0.45)
UK	0.2227 (0.1740)	1.8328 (0.7370)	1.5205 (0.2389)	0.56	0.44	18.6080 (17.3345)	(*)
USA	1.2222 (0.4274)	1.2140 (0.6266)	1.2780 (0.2986)	0.57	0.43	2.3296 (1.3728)	4.7 (0.82)
						Mean period	**3.9**
						Standard deviation	**1.2**

Table 3. Estimations for the multivariate IRW model (3), importance of the common cycle and duration of the cycle derived from the estimated parameter q_i according to equation (A5) for the post-war period 1950-2010 (Maddison data). (*) See note of Table 1.

These results have been compared with those obtained from the Penn World Tables (Feenstra *et al.*, 2013) for the same period (Table 4). Except for the year 1986, both common cycle components are broadly similar (see Figure 5). The importance of the common cyclical behavior is similar when compared with the Maddison data except for Australia (56%), Finland (50%) and, especially, Spain (91%), which is now greater. With respect to the duration of the business cycle, the more important differences appear in Australia, Germany, Norway and Spain. The mean duration is 4.3 years with a standard deviation of 2.1 years.

[Figure 5 about here]

	$\sigma^2_{\varepsilon_i}$	$\sigma^2_{\eta_i}$	γ_i	Importance of the common cycle w_i^c	Importance of the specific cycle w_i^s	$q_i = \frac{\gamma_i^2 + \sigma^2_{\eta_i}}{\sigma^2_{\varepsilon_i}}$	Duration of the cycles (years)
Australia	5.7894 (1.2992)	0.2382 (0.1828)	0.5554 (0.3021)	0.56	0.44	0.0944 (0.0682)	11.2 (2.07)
Austria	0.4269 (0.1332)	0.6109 (0.2372)	1.5472 (0.1324)	0.80	0.20	7.0381 (2.4765)	3.3 (0.43)
Belgium	0.5455 (0.1993)	0.6298 (0.3278)	2.5832 (0.1866)	0.91	0.09	13.3868 (6.6256)	2.5 (0.78)
Canada	2.2819 (0.6662)	1.6808 (0.7637)	1.3042 (0.2427)	0.50	0.50	1.4819 (0.6009)	5.4 (0.62)
Denmark	2.5442 (0.9533)	1.4476 (0.9821)	1.7049 (0.3828)	0.67	0.33	1.7114 (1.2414)	5.2 (1.07)

Finland	0.2636 (0.4079)	14.0641 (3.4046)	3.7689 (0.5403)	0.50	0.50	107.2302 (167.6622)	(*)
France	0.4928 (0.1596)	0.1807 (0.1575)	2.2143 (na)	0.96	0.04	10.3157 (3.5627)	2.8 (0.44)
Germany	0.4456 (0.2617)	1.3428 (0.7093)	2.1897 (0.1812)	0.78	0.22	13.7749 (9.4676)	2.4 (1.15)
Italy	1.1210 (0.3417)	0.8987 (0.4539)	2.2257 (0.2277)	0.85	0.15	5.2205 (1.3992)	3.7 (0.33)
Japan	1.5981 (0.4502)	5.6808 (1.1285)	2.0544 (0.2947)	0.43	0.57	6.1957 (na)	3.5 (na)
Netherlands	1.0617 (0.3334)	0.8571 (0.4411)	2.0645 (0.1355)	0.83	0.17	4.8217 (1.3122)	3.8 (0.34)
Norway	3.3826 (1.0939)	2.7158 (1.4159)	1.7177 (0.3830)	0.52	0.48	1.6751 (0.9879)	5.2 (0.88)
Spain	3.3707 (0.8671)	0.8587 (0.5136)	2.8887 (0.3274)	0.91	0.09	2.7303 (0.6682)	4.5 (0.33)
Sweden	1.8422 (0.6538)	1.4181 (0.8148)	1.8835 (0.2282)	0.71	0.29	2.6955 (1.4534)	4.5 (0.73)
Switzerland	0.5394 (0.2230)	1.5290 (0.5702)	2.5094 (0.1779)	0.80	0.20	14.5093 (6.3355)	2.3 (0.84)
UK	0.6026 (0.3312)	1.9644 (0.8697)	1.8762 (0.2934)	0.64	0.36	9.1023 (6.1012)	3.0 (0.83)
USA	1.6089 (0.4713)	1.4709 (0.6478)	1.0901 (0.3188)	0.45	0.55	1.6529 (0.9091)	5.2 (0.82)
						Mean period	**4.3**
						Standard deviation	**2.1**

Table 4. Estimations from the multivariate IRW model (3), the importance of the common cycle and duration of the cycle derived from the estimated parameter q_i according to equation (A5) for the post-war period 1950-2010 (Penn World Tables data, v 8.0). (*) See note of Table 1.

The cycles were accompanied by factors such as wars, population changes, and technology, as well as political, monetary and financial variables. In the 1970s economies suffered strong inflationary pressures as a consequence of lax monetary policy after the realization of oil shocks (Fernández de Pinedo 2012: 55-56). Banking, debt and, especially, monetary crises have shaken each decade since the 1970s, intensifying the number of bank failures in the following decades (Kinderberger 1978). Finland, Norway and Sweden suffered from a monetary and banking crisis in the 1990s, along with the persistent crisis in Japan from 1985 to 1990. However, Eastern Europe and Russia also suffered during their transition to capitalism. The values of national currencies have changed frequently since the 1970s (Kinderberger 1978). Western Europe reached some degree of stability when on the 1st of January 1999, the euro became, along with the dollar and the yen, an international currency; however, business and credit fluctuate, as did crises, in a natural way.

4. Concluding remarks

As noted previously, HP filtering with an *a priori* smoothing parameter implies a selection of frequencies that may distort the analysis of business cycle duration and phases by the exclusion and/or leakage of frequencies. The estimation method proposed here avoids this problem by estimating the signal-to-noise ratio; that is, it allows the data to "speak for themselves". Additionally, the IRW model (both univariate and multivariate) incorporates, in a coherent framework, the possibility of estimating simultaneously both the classical business cycle and the growth cycle implied by the estimated signal-to-noise ratio.

When applied to a sample of Maddison's GDP series, a classical business cycle of a duration in the range of 4-7 years (Juglar-type cycles) is found, and there is no evidence of long swings or Kuznets-type cycles. Cyclical convergence is evident and very strong after 1950, when cyclical phases are synchronized across economies (one factor grouping all of the economies was found), and the standard deviation of the cyclical period is approximately one year.

In the pre-war and inter-war periods, a minor economic integration, the specific effects of the world wars and the more noisy content of the series weaken the cyclical coherence. As O'Rourke and Williamson (1995: 7) noted, "global openness and convergence seem to be positively correlated; global autarky and convergence seem to be negatively correlated". Not all regions are synchronized with the national business cycles (Owyang et al. 2005), and not all economies are synchronized, but cyclical convergence seems to depend on international capital and trade flows if the effects of the industrial revolution (the first, second, and third) and the globalization process among national economies are considered.

Although European countries entered the nineteenth century with mercantilist policies that consolidated nation-states, a century later, all economies were linked by the need to validate international rules to regulate economic activity at a global level. Regional economic agreements in the inter-war period (Oslo Group, Clearing Agreements, Rome or Ottawa Agreements or even Cartel Agreements) demonstrated the crucial significance of cooperation over regional variations. The two world wars highlighted how easy it is to alter the domestic economic structure and international flows. Although the catch-up to modern economic growth followed diverse rhythms and timeframes, the negotiations before the end of WWII to gestate a world order and prevent another inter-war period evidenced the importance of cooperation and multilateralism, both foundations of long globalization cycles.

Finally, although our estimations do not locate long swings, we cannot discard the existence of Kondratieff-type cycles (Metz 2011). Moreover, when investigating long-term processes affecting economic growth, some interesting extensions of this work would include the relationship between demographic stagnation (Gonzalo et al. 2013) and the decreasing profile of (per capita) growth rates during the post-war period. Some tentative hypotheses concern the existence of a demographic dividend (e.g., Roa and Cendejas 2007). In any case, unobserved component modeling has proved to be a very useful tool for cliometric analysis due to the explicit consideration of long-term and medium-term (cycles) economic processes when the models are interpreted in the frequency domain.

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FIGURES

Figure 1. Spectral gains of the filters of μ_t (in red), g_t (in blue) and a_t (in green) for $q = 0.01$. Horizontal axis: period in units of time.

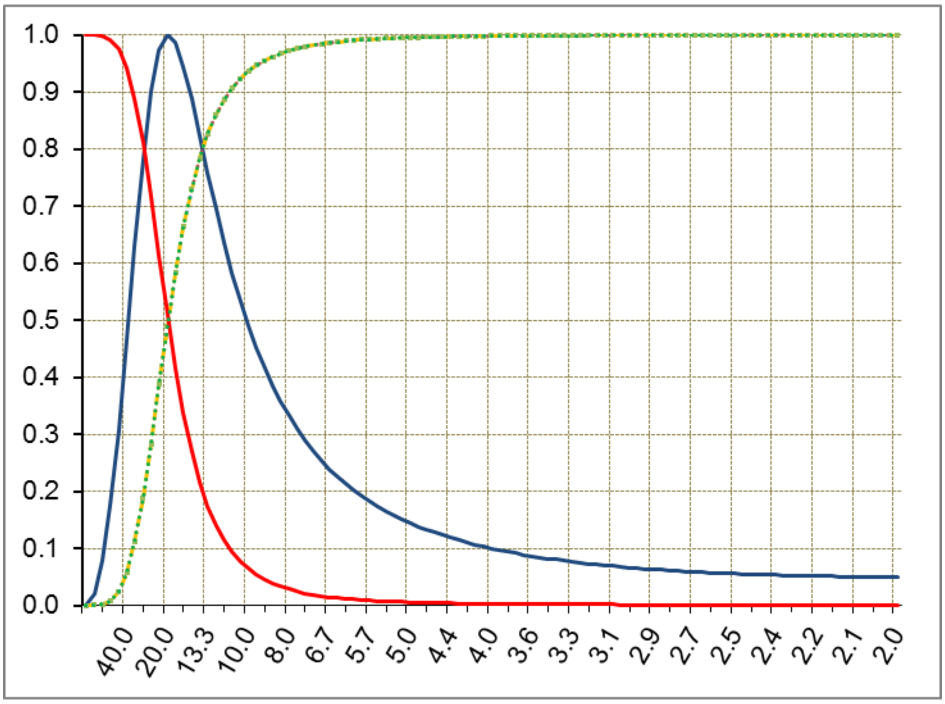
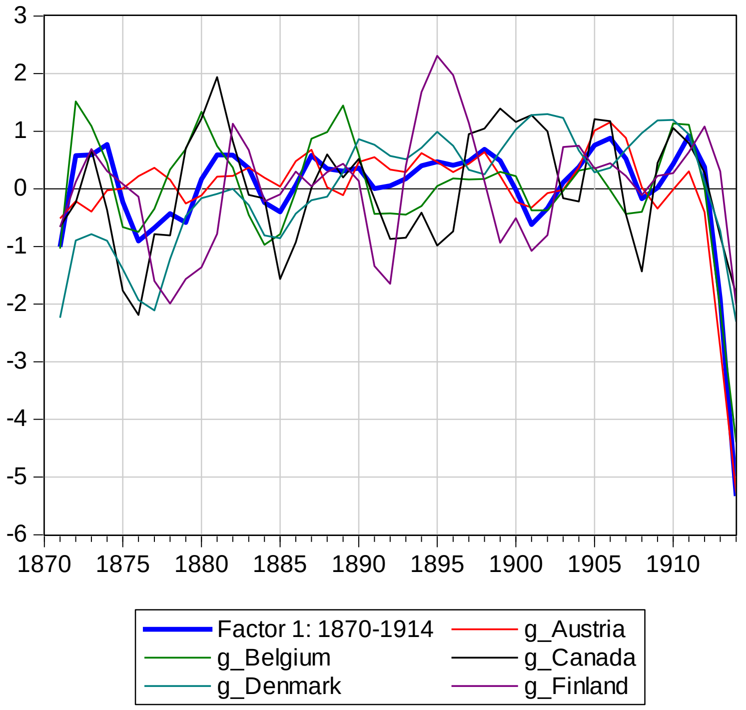


Figure 2. Common factors and underlying growth for the period 1870-1914. Normalized scale.



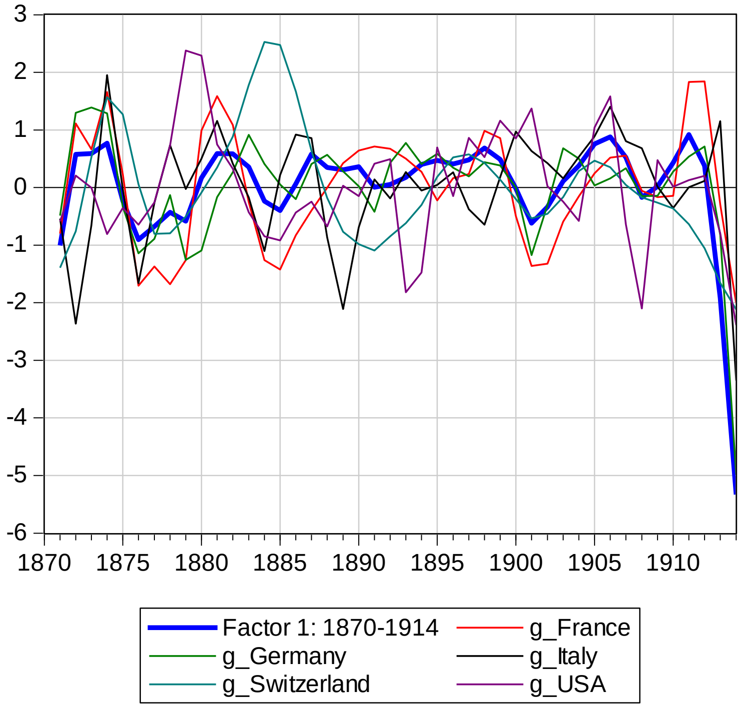
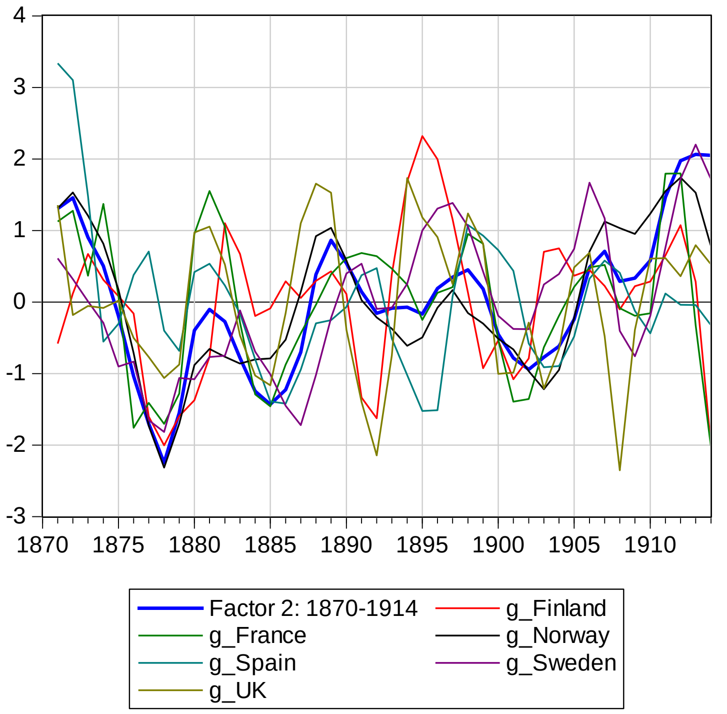


Figure 2 (cont.).



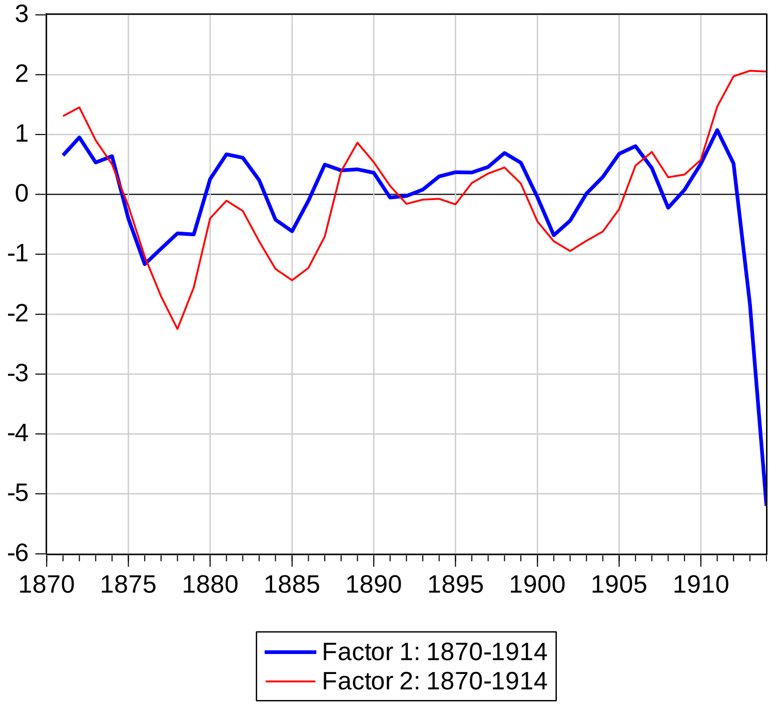
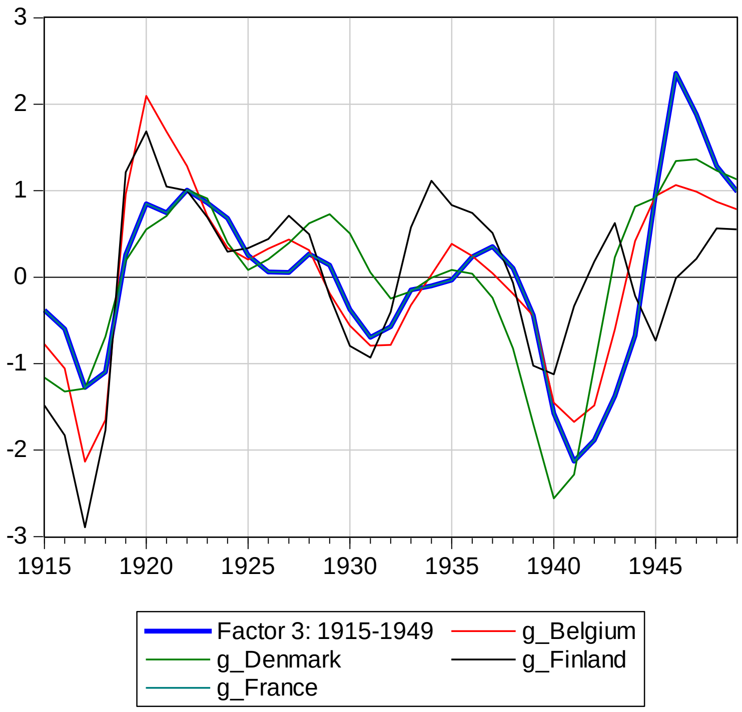
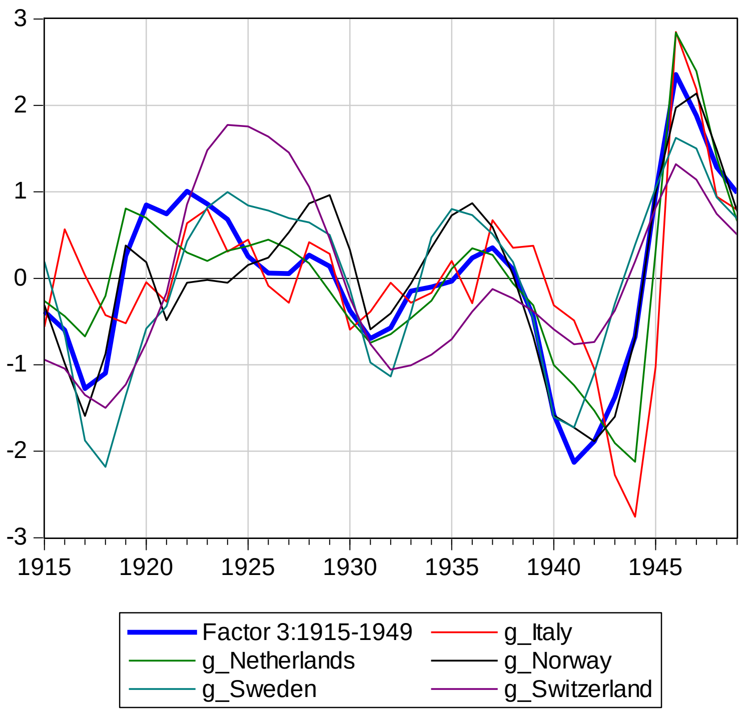


Figure 3. Common factors and underlying growth for the period 1915-1949. Nomalized scale.





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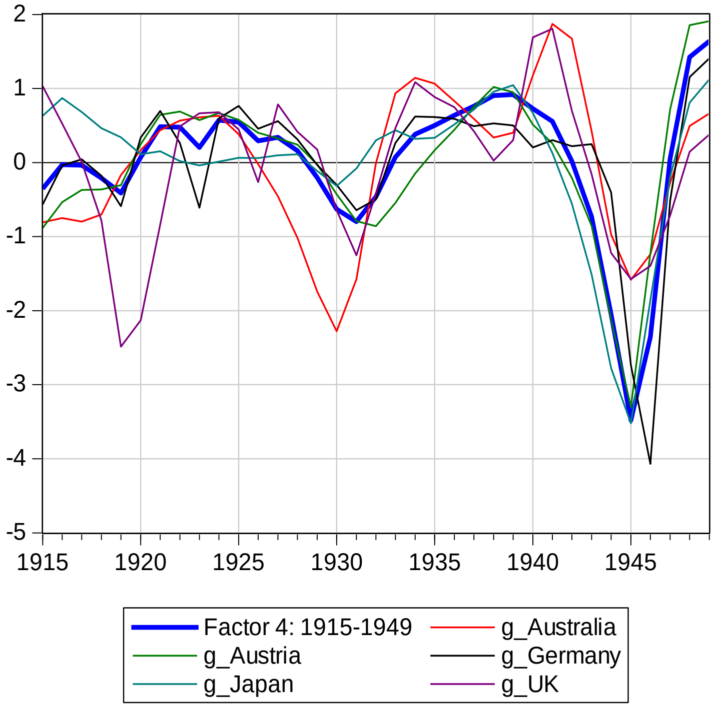


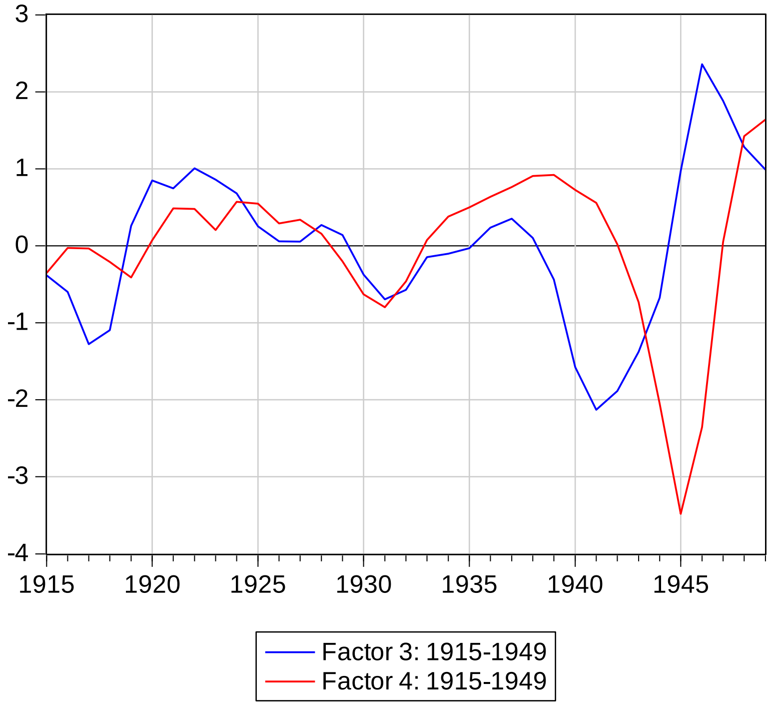
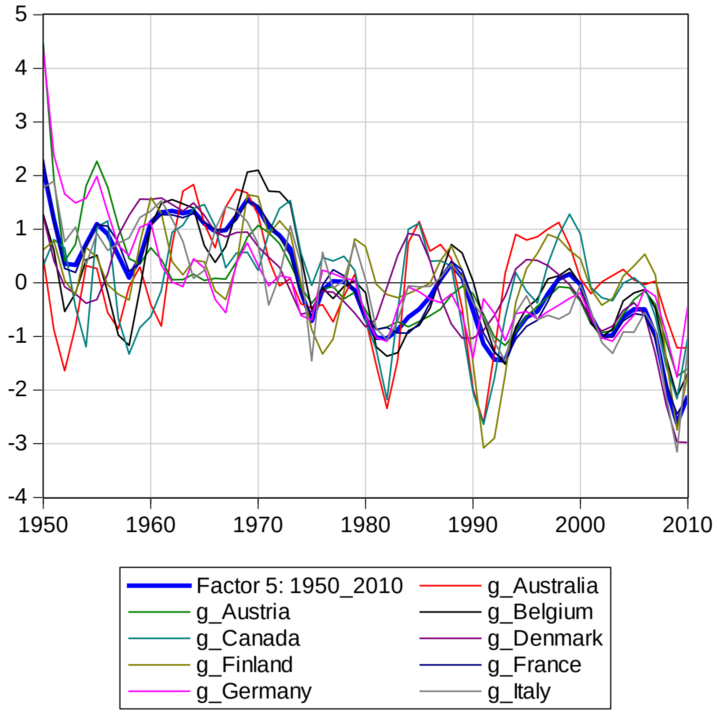


Figure 4. Common factors and underlying growth for the period 1950-2010. Normalized scale.



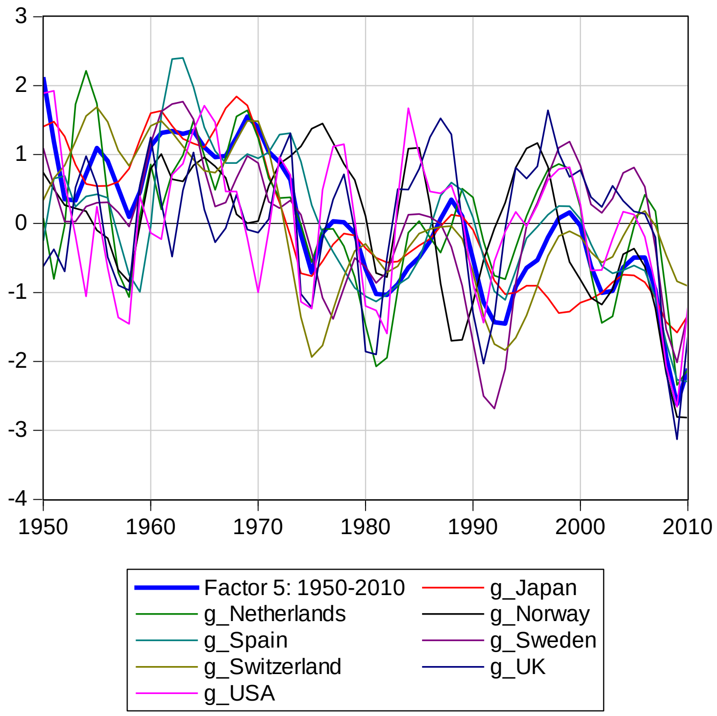
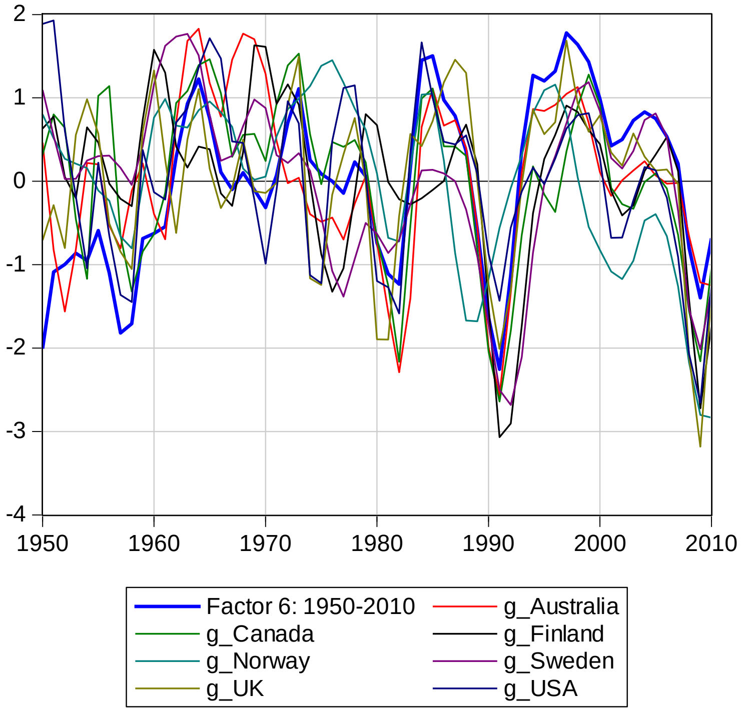


Figure 4 (cont.).



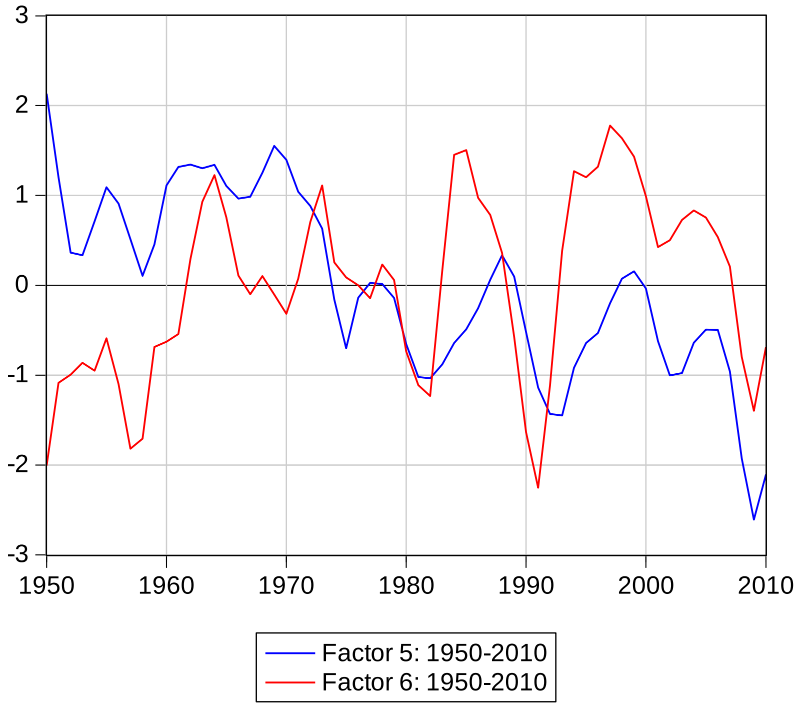
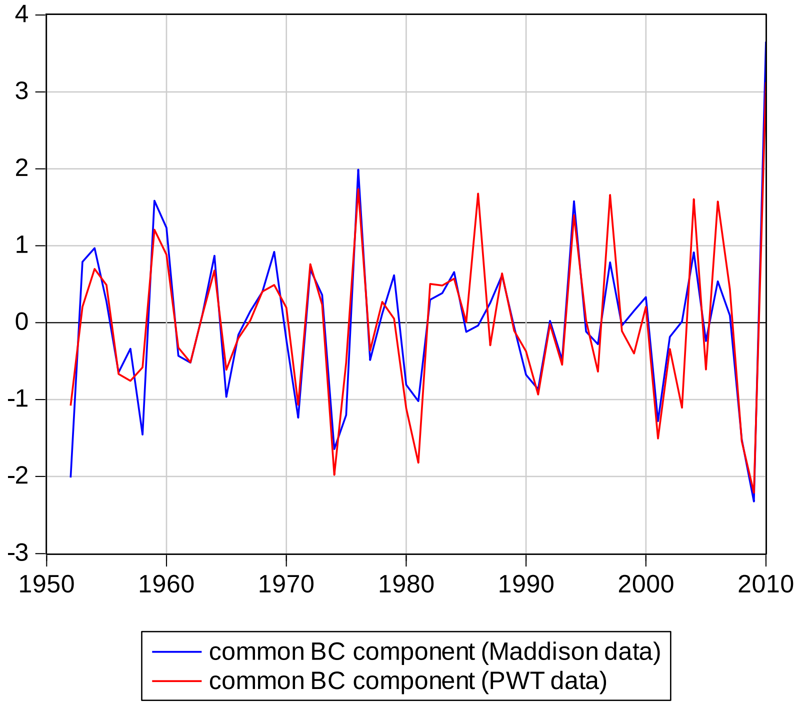


Figure 5. Common business cycle factors ($\hat{a}_t$) from Maddison and PWT data for the period 1950-2010.



Appendix A: Spectral gains of the filters for the unobserved components

The spectral gain of a filter measures the increase in amplitude of any specific frequency component of a time series. It is obtained by the Wiener-Kolmogorov (WK) formula (Whittle, 1983). To this end, we depart from (1a), in which the signal $\mu_t = \frac{\eta_{t-2}}{(1-L)^2}$. The WK filter (of a doubly infinite realization of a time series) that provides the minimum mean squared error of the signal is given by the ratio of the autocovariance generating functions of the signal μ_t and the series y_t. For the trend component, the filter is

$$\hat{\mu}_t = \frac{\dfrac{\sigma_\eta^2}{(1-L)^2(1-L^{-1})^2}}{\dfrac{\sigma_\eta^2}{(1-L)^2(1-L^{-1})^2} + \sigma_\varepsilon^2} y_t = \frac{q}{q+(1-L)^2(1-L^{-1})^2} y_t = \frac{q}{q+|1-L|^4} y_t \qquad \text{(A1)}$$

where L^{-1} is the forward operator ($L^{-k} y_t = y_{t+k}$) and the convention $(1-L)(1-L^{-1}) = |1-L|^2$ is adopted. The spectral gain of the filter of μ_t is obtained by doing $L = e^{-i\omega}$ in (A1), where $i = \sqrt{-1}$ is the imaginary number and ω the frequency, obtaining

$$G_\mu(\omega) = \frac{q}{q+4(1-\cos\omega)^2} . \qquad \text{(A2)}$$

For the growth component g_t, (1a) is expressed as $y_{t+1} = \frac{g_t}{1-L} + \varepsilon_{t+1}$ with the signal $g_t = \frac{\eta_{t-1}}{1-L}$. The resulting WK filter is

$$\hat{g}_t = \frac{\dfrac{\sigma_\eta^2}{(1-L)(1-L^{-1})}}{\dfrac{\sigma_\eta^2}{(1-L)^2(1-L^{-1})^2} + \sigma_\varepsilon^2} y_{t+1} = \frac{(1-L)(1-L^{-1})q}{q+(1-L)^2(1-L^{-1})^2} y_{t+1} = \frac{|1-L|^2 q}{q+|1-L|^4} y_{t+1} \qquad \text{(A3)}$$

for which the spectral gain is

$$G_g(\omega) = \frac{2(1-\cos\omega)q}{q+4(1-\cos\omega)^2} \qquad \text{(A4)}$$

This gain has a maximum at the frequency

$$\omega_{\max} = \arccos\left(1 - \left(\frac{q}{4}\right)^{1/2}\right) \tag{A5}$$

For example, for $q = \lambda^{-1} = \{0.001,\ 0.01,\ 0.1,\ 1,\ 10\}$, the corresponding periods $p = \dfrac{2\pi}{\omega_{\max}}$ are $p = \{35.3,\ 19.8,\ 11.0,\ 6.0, 2.9\}$ units of time.

For the acceleration component, (1a) is expressed as $y_{t+2} = \dfrac{a_t}{(1-L)^2} + \varepsilon_{t+2}$ with the signal $a_t = \eta_t$; then, the WK filter is

$$\hat{a}_t = \frac{\sigma_\eta^2}{\dfrac{\sigma_\eta^2}{(1-L)^2(1-L^{-1})^2} + \sigma_\varepsilon^2} y_{t+2} = \frac{(1-L)^2(1-L^{-1})^2 q}{q + (1-L)^2(1-L^{-1})^2} y_{t+2} = \frac{|1-L|^4 q}{q + |1-L|^4} y_{t+2} \tag{A6}$$

In addition, in the frequency domain,

$$G_a(\omega) = \frac{4(1-\cos\omega)^2 q}{q + 4(1-\cos\omega)^2} \tag{A7}$$

The HP filter is the optimal filter when the trend follows an IRW (King and Rebelo, 1993). In the context of HP filtering, the cycle (growth cycle) is defined as the deviation with respect to the trend $\varepsilon_t = y_t - \mu_t$, and the corresponding WK filter is

$$\hat{C}_t^{HP} = y_t - \hat{\mu}_t = \left(1 - \frac{q}{q + |1-L|^4}\right) y_t = \frac{|1-L|^4}{q + |1-L|^4} y_t \tag{A8}$$

A comparison of (A2), (A4), (A7) and (A8) allows the verification of

$$G_{HP}(\omega) = \frac{4}{q}(1-\cos\omega)^2 G_\mu(\omega) = \frac{2}{q}(1-\cos\omega) G_g(\omega) = \frac{1}{q} G_a(\omega) \tag{A9}$$

with $G_{HP}(\omega)$ the spectral gain of the HP filter given q.

Appendix B: State space representations of the univariate and the multivariate models

State space representation consists of two equations. The measurement equation relates the observed variable with the unobserved components and the observation noise. For IRW model (1), basically coincides with equation (1a)

$$\left[y_t\right] = \begin{bmatrix} 1 & 0 & 0 \end{bmatrix} \begin{bmatrix} \mu_t \\ g_t \\ a_t \end{bmatrix} + \left[\varepsilon_t\right] \qquad \text{(B1)}$$

The state transition equation represents the dynamics of the unobserved components. According to equations (1b) to (1d), this is

$$\begin{bmatrix} \mu_t \\ g_t \\ a_t \end{bmatrix} = \begin{bmatrix} 1 & 1 & 0 \\ 0 & 1 & 1 \\ 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} \mu_{t-1} \\ g_{t-1} \\ a_{t-1} \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ \eta_t \end{bmatrix} \qquad \text{(B2)}$$

Gaussianity and orthogonality assumptions of the error terms imply that $\varepsilon_t \sim N\left(0,\sigma_\varepsilon^2\right)$ and $\xi_t \sim N\left(0_{3\times 1},Q\right)$, where $\xi_t = \begin{bmatrix} 0 \\ 0 \\ \eta_t \end{bmatrix}$ and $Q = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & \sigma_\eta^2 \end{bmatrix}$. By doing $H = \begin{bmatrix} 1 & 0 & 0 \end{bmatrix}$, $\beta_t = \begin{bmatrix} \mu_t \\ g_t \\ a_t \end{bmatrix}$ and $F = \begin{bmatrix} 1 & 1 & 0 \\ 0 & 1 & 1 \\ 0 & 0 & 0 \end{bmatrix}$, the state space representation of the system (B1)-(B2) in compact form is

$$\left.\begin{aligned} y_t &= H\beta_t + \varepsilon_t \\ \beta_t &= F\beta_{t-1} + \xi_t \end{aligned}\right\} \qquad \text{(B3)}$$

Estimation of the vector of variances $\left\{\sigma_\varepsilon^2,\sigma_\eta^2\right\}$ is obtained by maximizing the likelihood function of the one-step ahead prediction errors (Harvey, 1989; Durbin and Koopman, 2001).

For the multivariate IRW model (3) and for illustrative purposes, let us assume two time series, $i=1,\ 2$, with specific acceleration components $a_{1,t}$ and $a_{2,t}$, and that the common acceleration component, a_t, follows an autoregressive model such as $a_t = \phi a_{t-1} + \eta_t$. From equation (3a), we have that the measurement equation relating observed variables with unobserved components is

$$\begin{bmatrix} y_{1,t} \\ y_{2,t} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} \mu_{1,t} \\ g_{1,t} \\ \mu_{2,t} \\ g_{2,t} \\ a_t \\ a_{1,t} \\ a_{2,t} \end{bmatrix} + \begin{bmatrix} \varepsilon_{1,t} \\ \varepsilon_{2,t} \end{bmatrix} \qquad \text{(B4)}$$

According to equations (3b) to (3e), the state transition equation, is

$$\begin{bmatrix} \mu_{1,t} \\ g_{1,t} \\ \mu_{2,t} \\ g_{2,t} \\ a_t \\ a_{1,t} \\ a_{2,t} \end{bmatrix} = \begin{bmatrix} 1 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & \gamma_1 & 1 & 0 \\ 0 & 0 & 1 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & \gamma_2 & 0 & 1 \\ 0 & 0 & 0 & 0 & \phi & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} \mu_{1,t-1} \\ g_{1,t-1} \\ \mu_{2,t-1} \\ g_{2,t-1} \\ a_{t-1} \\ a_{1,t-1} \\ a_{2,t-1} \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ \eta_t \\ \eta_{1,t} \\ \eta_{2,t} \end{bmatrix} \qquad \text{(B5)}$$

Gaussianity and orthogonality assumptions of the error terms imply that $\varepsilon_t \sim N\left(0_{2x1}, R\right)$ and $\xi_t \sim N\left(0_{7x1}, Q\right)$, where $\varepsilon_t = \begin{bmatrix} \varepsilon_{1,t} \\ \varepsilon_{2,t} \end{bmatrix}$, $\xi_t = \begin{bmatrix} 0_{4x1} \\ \eta_t \\ \eta_{1,t} \\ \eta_{2,t} \end{bmatrix}$, $R = \begin{bmatrix} \sigma^2_{\varepsilon_1} & 0 \\ 0 & \sigma^2_{\varepsilon_2} \end{bmatrix}$, $Q = \begin{bmatrix} 0_{4x4} & 0_{4x1} & 0_{4x1} & 0_{4x1} \\ 0_{1x4} & 1 & 0 & 0 \\ 0_{1x4} & 0 & \sigma^2_{\eta_1} & 0 \\ 0_{1x4} & 0 & 0 & \sigma^2_{\eta_2} \end{bmatrix}$ and 0_{mxn} is a mxn matrix of ceros. By doing $y_t = \begin{bmatrix} y_{1,t} \\ y_{2,t} \end{bmatrix}$, $H = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 \end{bmatrix}$, $\beta_t = \begin{bmatrix} \mu_{1,t} \\ g_{1,t} \\ \mu_{2,t} \\ g_{2,t} \\ a_t \\ a_{1,t} \\ a_{2,t} \end{bmatrix}$ and

$F = \begin{bmatrix} 1 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & \gamma_1 & 1 & 0 \\ 0 & 0 & 1 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & \gamma_2 & 0 & 1 \\ 0 & 0 & 0 & 0 & \phi & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$, the state space representation of the system (B4)-(B5) in compact form follows the general form (B3). Estimation of the vector of parameters $\left\{\sigma^2_{\varepsilon_i}, \sigma^2_{\eta_i}, \gamma_i, \phi\right\}$ is obtained as previously outlined for the univariate model.